DESIGN AND ANALYSIS OF AIR CRAFT WING USING DIFFERENT COMPOSITE MATERIALS

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Abstract:

An aircraft wing is a type of fin that produce lift, while moving through air or. As such, wings have efficient cross-sections that are subject to aerodynamic forces and act as an air foils. A wing's aerodynamic quality is expressed as its lift-to-drag ratio. The lift a wing generates at a given speed and angle of attack can be one to two orders of magnitude greater than the total drag on the wing. A high lift-to-drag ratio requires a significantly smaller thrust to propel the wings through the air at sufficient lift. In design and finite element analysis of aircraft wing is designed and modeled in 3D software SW 2024. The materials used for aircraft wings are mostly metallic alloys. In this project, the materials are replaced by composite materials S Glass, Carbon/Epoxy and Kevlar 49. Static analysis is done to determine the stresses produced by applying loads. Modal analysis is done on the aircraft wing to determine the frequencies and deformations, stress due to frequencies.

Keywords: Aero plane wing, SW 2024, ANSYS 2024R1, static structural, modal analysis

1.0 INTRODUCTION

The wing is a primary structural component of aircrafts (air breathing engines) which is used to produce lift force during flight. When the engine is started air is sucked into the compressor through the inlet increasing pressure ratio at the exit of the compressor. Then air and fuel is mixed inside combustion chamber and burnt. When high pressure, high temperature gases is accelerated through the nozzle, thrust force is produced which propels the aircraft in forward motion. Due to this forward motion, air flows over the wing which is aerodynamic in shape. Due to the aerodynamic shape of the wing along with Bernoulli‟s principle the velocity of flow is less at bottom of the wing and high at top of wing. Due to this pressure difference is created between top and bottom surface of wing and thus lift is generated. Wing must have high strength to weight ratio, high fatigue life since it is subjected to alternate repeated loadings during flight. A fixed-wing aircraft is an aircraft, such as an aero plane, which is capable of flight using wings that generate lift caused by the vehicle's forward airspeed and the shape of the wings. Fixed-wing aircraft are distinct from rotary-wing aircraft in which the wings form a rotor mounted on a spinning shaft, in which the wings flap in similar manner to a bird. Glider fixed-wing aircraft, including free-flying gliders of various kinds and tethered kites, can use moving air to gain height. Powered fixed-wing aircraft that gain forward thrust from an engine (aero planes) include powered par gliders, powered hang gliders and some ground effect vehicles.

Aircraft wings:

Aircraft wings are an essential component of an airplane's design, as they are responsible for generating the lift needed for flight. Wings are typically attached to the fuselage of the aircraft and come in various shapes and sizes depending on the type of aircraft.

- Wings are designed with an airfoil shape, which is optimized to produce lift efficiently by creating a pressure difference between the upper and lower surfaces of the wing. This pressure difference, along with the forward motion of the aircraft, results in lift being generated to support the aircraft in flight.
- Additionally, wings can also house fuel tanks, control surfaces like ailerons and flaps for maneuvering, and other systems depending on the specific aircraft's design and function.

Advantages of aircraft wing

Aircraft wings play a crucial role in the flight of an aircraft. Here are some advantages of aircraft wings:

Lift Generation: Wings are designed to generate lift, which is the force that enables an aircraft to overcome gravity and stay airborne. The shape and angle of the wing create a pressure difference between the upper and lower surfaces, resulting in lift.

Control: Wings help in controlling the aircraft's movement during flight. Ailerons, located on the wings, are used to roll the aircraft, while elevators control pitch. These elements provide stability and maneuverability to the aircraft.

Fuel Efficiency: Well-designed wings can improve the overall fuel efficiency of an aircraft. Modern aircraft wings are designed to reduce drag, which helps in saving fuel during flight.

Safety: Wings often incorporate safety features such as winglets, which reduce drag and increase fuel efficiency. They also contribute to better aerodynamic performance and stability during flight.

Structural Support: Wings provide structural support to the aircraft. They are designed to withstand various forces experienced during flight, such as lift, drag, and turbulence, ensuring the safety and integrity of the aircraft.

Storage: Some aircraft wings have fuel tanks built into them, allowing for more efficient use of space within the aircraft's structure.

Problem Statement:

Aircraft wings are built to withstand the extreme weather conditions that occur during flight and the turbulence that is created should not affect the performance of the wing. Hence material selection is an important parameter to be considered when designing an aircraft wing. Composites made of carbon fibre has the capacity to serve this purpose due to its high stiffness, high strength and less weight.

Objectives:

- To study the Aircraft wing profile using different materials
- To design the model done by using SW 2024 With different geometric conditions
- To Analyse the blade profile using structural and modal analysis using various boundary conditions

2.0 LITERATURE REVIEW

The purpose of the literature survey is to study the works of different researchers concerned with the detailed study of the air craft wing design. Also to find out the scope for any new methods of design by which the design process is made simple, robust, less time consuming and cost effective. The literature survey is entirely based on the previous research methods. It is desired to explore the application of the fundamental properties such as vibration which plays an important role in the failure of the structure. Hence the literature survey is carried out emphasizing the structural design of the aircraft wing subjected to vibration. **Atif Laiche and Allaoua Boulahia [1]** The analysis, implementation and modeling of aircraft wing's charges are presented. The integration of different mathematical equations is described to identify each load that acts on the wing structure for the sake of obtaining the overall load profile. **Abdulkareem Sh. Mahdi Al-Obaidi [2],** The effect of various wing geometry parameters on lift generation at supersonic speeds has been studied and analyzed. These parameters include the aspect ratio, taper ratio, leading edge sweep angle, relative thickness and the airfoil shape. The parametric study considered only four wing plan forms which were the straight rectangular, sweptback, delta and trapezoidal wings. **Li Jixinga,Ning Taoa,*, Xi Pinga, Wang Tiana[3]** This paper presents an approach to implement rapid design, modeling, and automated adjustment for missile body structures by describing missile body structures' arrangement information and model information with parameters **Youxu Yang, Zhigang Wu, Chao Yang [4],** A multi-plate model based on Ritz method and penalty function technique is developed to model complex wing configurations formed by wing segments in different planes. Each wing segment is modeled as a plate element basing on the first-order shear deformation plate theory. The penalty function technique is used to impose displacement compatibility along sides of adjacent plate elements. **Sudhir Reddy Konayapalli, Y. Sujatha [5],** In the present study, a general aviation airplane is designed and analyzed. The design process starts with a sketch of how the airplane is envisioned. Weight is estimated based on the sketch and a chosen design mission profile. A more refined method is conducted based on calculated performance parameters to achieve a more accurate weight estimate which is used to acquire the external geometry of the airplane. **Nataraj Kuntoji , Dr. Vinay V. Kuppast [6],** The wing analysis is carried out by using computer numerical analysis tool, viz., CAD/CAE and CFD. The optimization of the aircraft wing is effectively achieved by considering different material properties, loading conditions and dimensions with different flying conditions. **M. Ganesh, G Hima Bindu, A. Sai Kumar [7],** In this work, failure modes and buckling loads of composite plate under uniformly distributed loading and deflection is investigated by using analytical and theoretical approaches. A 3-D finite-elements model was also built which takes into consideration the exact geometric configuration and the orthotropic properties of the composite plate. **A. Ramesh Kumar et al [8]** Design Of An Aircraft Wing Structure For Static Analysis And Fatigue Life in his paper a wing structure of a trainer aircraft with skin, spars and ribs was considered for the detailed analysis. Stress analysis of the whole wing section is carried out to compute the stresses at spars and ribs due to the applied pressure load. **M. Ganesh, G Hima Bindu [9]** In this work, failure modes and buckling loads of composite plate under uniformly distributed loading and deflection is investigated by using analytical and theoretical approaches. A 3-D finite-elements model was also built which takes into consideration the exact geometric configuration and the orthotropic properties of the composite plate. **V. Saran, V. Jayakumar [10]** To analysis of natural frequency for avoiding resonance on the material to prevent failure and to simulate according to the boundary conditions. The Vibrations of an aircraft wing structure is analyzed using CATIA and ANSYS software.

3.0 METHODOLOGY

A wing's aerodynamic quality is expressed as its lift-to-drag ratio. The lift a wing generates at a given speed and angle of attack can be one to two orders of magnitude greater than the total drag on the wing. A high lift-to-drag ratio requires a significantly smaller thrust to propel the wings through the air at sufficient lift. The requirements for the aircraft wing are High stiffness, High strength, High toughness and Low weight.

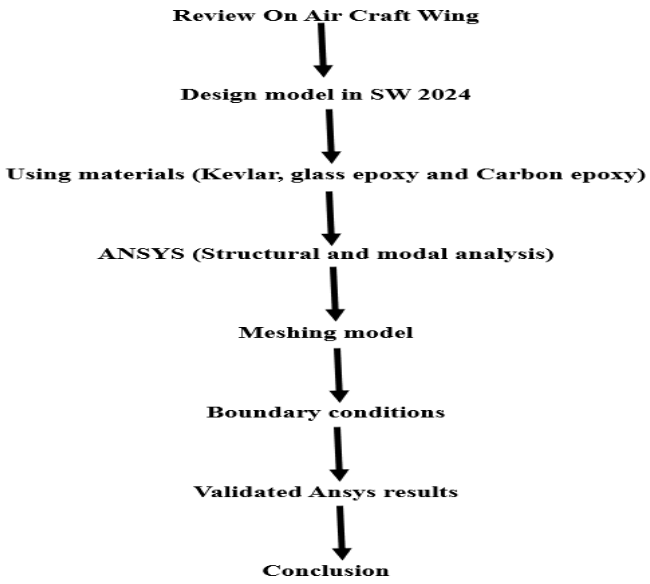

Figure 1: Design flow chart

working principle of aircraft

The working principle of an aircraft wing involves the generation of lift through aerodynamic forces. Here is a simplified explanation of how aircraft wings work:

Shape of the Wing: The shape of an aircraft wing is carefully designed to create a pressure difference between the upper and lower surfaces of the wing. The curved upper surface and relatively flat lower surface cause the air to move faster over the top, creating lower pressure compared to the bottom surface. This pressure difference generates lift.

Bernoulli's Principle: According to Bernoulli's principle, faster-moving air creates lower pressure. As the air flows over the curved upper surface of the wing at a higher speed compared to the lower surface, the pressure difference results in lift.

Angle of Attack: The angle at which the wing meets the oncoming air, known as the angle of attack, is crucial for lift generation. By adjusting the angle of attack, the pilot can control the amount of lift produced by the wing.

Airfoil Design: The cross-sectional shape of the wing, known as the airfoil, is optimized for efficient lift generation. Airfoils are designed to generate the maximum lift with the least amount of drag.

Control Surfaces: Control surfaces such as ailerons and flaps on the wings help the pilot control the aircraft's movement. Ailerons are used to bank or roll the aircraft, while flaps can increase lift during takeoff and landing.

Design and Construction

Aircraft is designed according to many factors such as, customer and manufacturer demand, safety protocols and physical and economic constraints. For many types of aircraft the design process is regulated by national airworthiness authorities

Air craft wing design

It is the process of defining the form and specifications of a wind turbine to extract energy from the wind. A wind turbine installation consists of the necessary systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop, and control the turbine. This article covers the design of horizontal axis wind turbines (AIRCRAFT WING) since the majority of commercial turbines use this design.

Boundary Condition: The loads and boundary conditions along with finite element model are shown in figure 3 below. One end of the wing is fixed because it is embedded inside the fuselage and other end is left free with 6 degree of freedom. Pressure force of 500Pa is applied at the bottom surface of the wing at center of pressure Center of pressure is a point at which total pressure is assumed to be act.

Design calculations:

All up weight of the aircraft considered for the analysis is 2000 kg (aircraft 4- seater)

Design load factor = 3

Total load acting on air craft = 2000 x 3 = 6000 kg

FOS = 1.5

Design load = 6000 x 1.5 = 9000 kg

Lift load on the wing = 80% of total load

= 0.8 x 9000

= 7200 kg

Load acting on each wing = 7200/2

= 3600kg

= 35303.94 N

Pressure = 35303.94

=3922.5 pa

ρ = air density = 1.22 kg/m^3

inlet velocity = 18 m/sec

$$L = \frac{1}{2}\rho v^2 \times C_l \times A = 0.5 \times 1.225 \times 18^2 \times 0.5 \times 5 \times 0.1 = 49.61\text{N}$$

$$D = \frac{1}{2}\rho v^2 \times C_d \times A = 0.5 \times 1.225 \times 18^2 \times 0.008 \times 5 \times 0.1 \times 2$$

$$= 15.87\text{N}$$

INTRODUCTION TO SOLID WORKS:

SolidWorks is one of the products of SolidWorks Corporation, which is powered by Dassault Systems 3D experience platform. SolidWorks mechanical design automation software is a feature-based, parametric solid modeling design tool that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings.

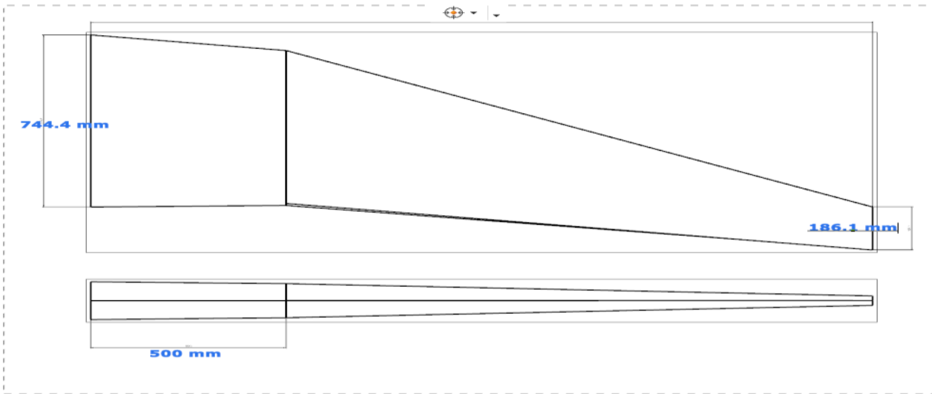

Figure 2: Geometric view

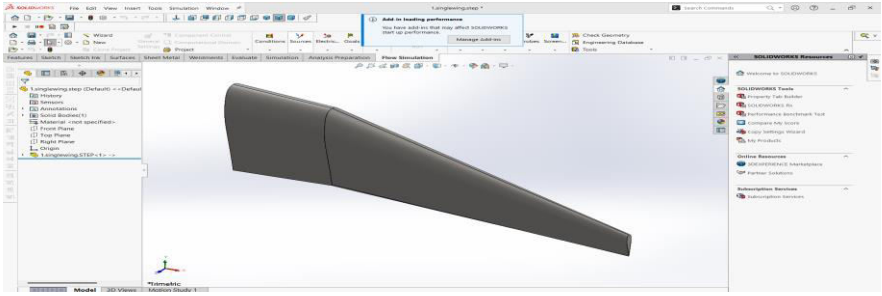

Figure 3: Design model

4.0 RESULTS AND DISCUSSIONS

Composed of a combination of materials such as carbon fibers and epoxy resins, they offer a unique set of properties that enable wind turbine blades to harness wind energy more efficiently.

Engineering analysis relies heavily on numerical simulation-based methods, which are characterized by low costs, accurate, results and quick processes. the numerical simulation techniques are being increasingly implemented, partly as a result of technological advancements. Numerical simulations are becoming significantly more advanced due to the flexibility of its implementation

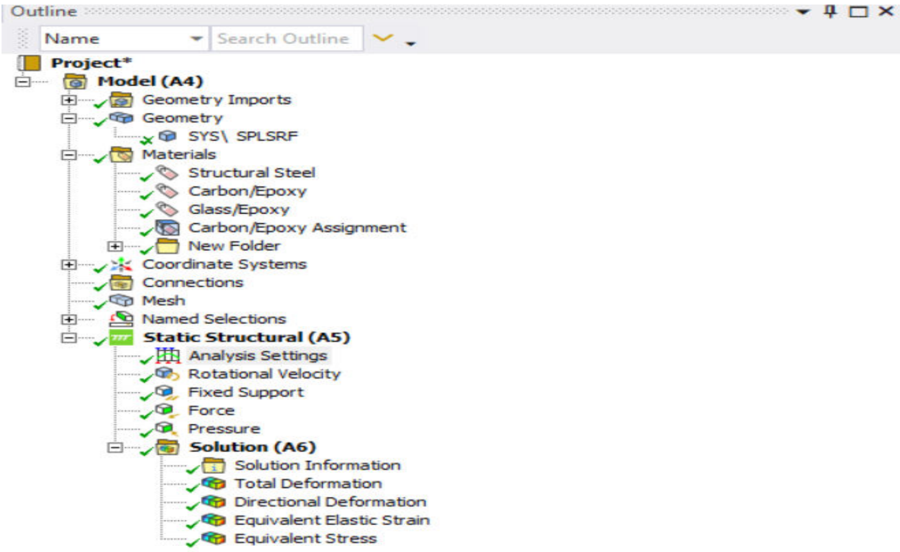

Figure 4: Structural solution layout

Meshing is the process of breaking down the geometric shape of an object into numerous elements which properly defines the overall physical shape of the object. The conditions are applied to these elements and the solution is calculated and interpolated across the entire domain. Generating a high-quality mesh is one of the most critical factor that should be considered to ensure accuracy in simulation

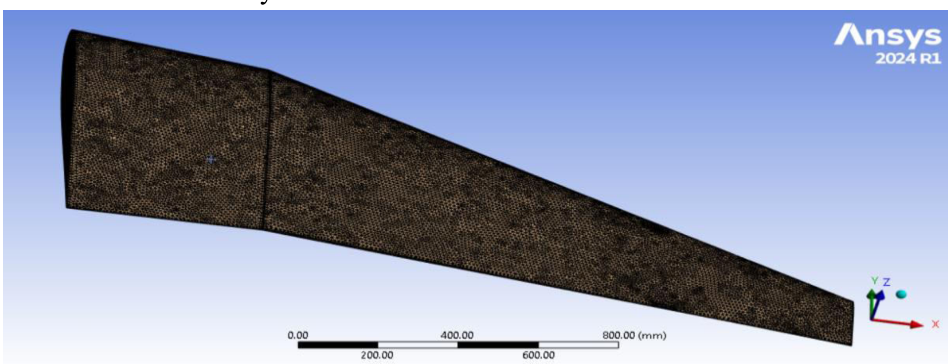

Figure 5: Meshed model

Static structural analysis of Aircraft wing Using Kevler 49 material

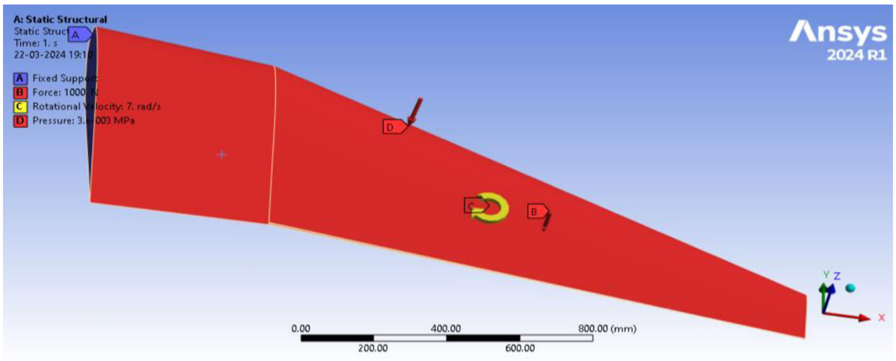

Figure 6: Properties Assignment

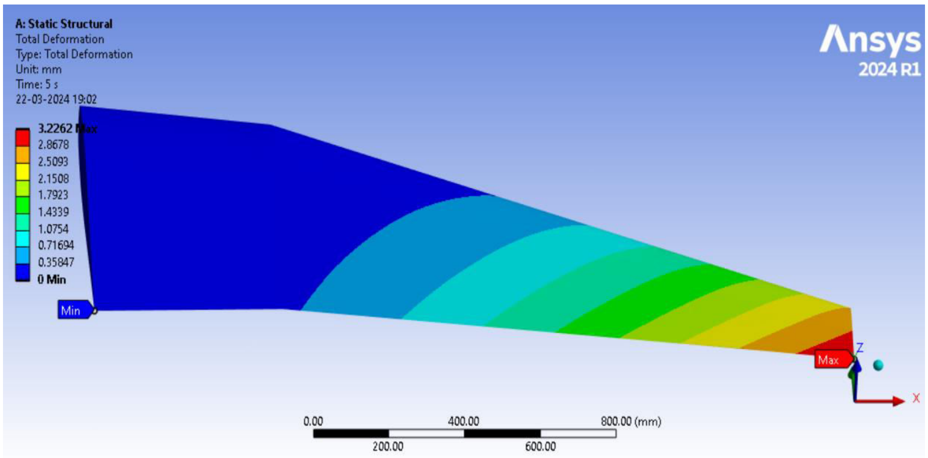

Figure 7: Total Deformation

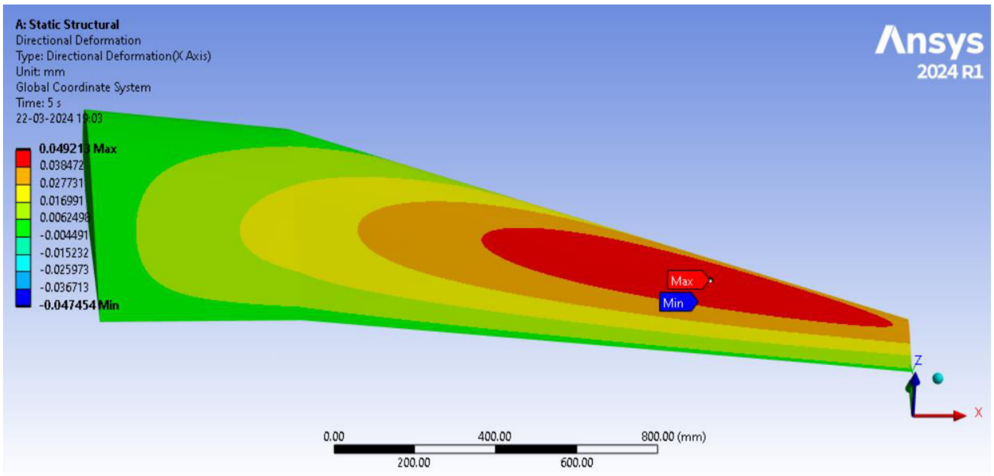

Figure 8: Directional deformation

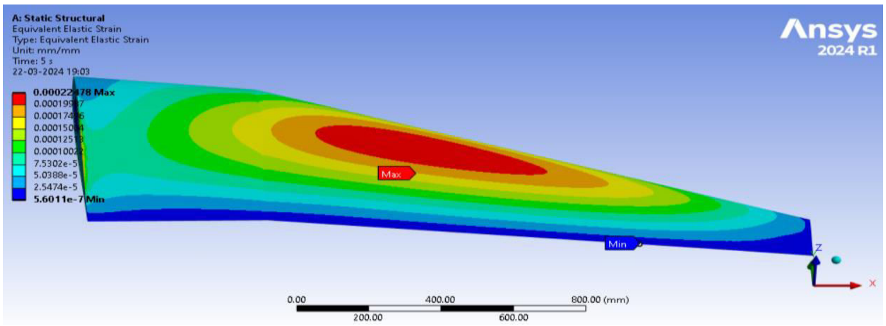

Figure 9: Equivalent elastic strain

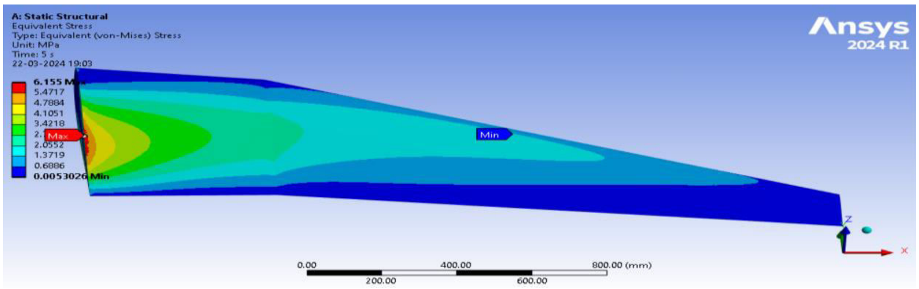

Figure 10: Equivalent stress

Static structural analysis of Aircraft wing Using Carbon/epoxy material

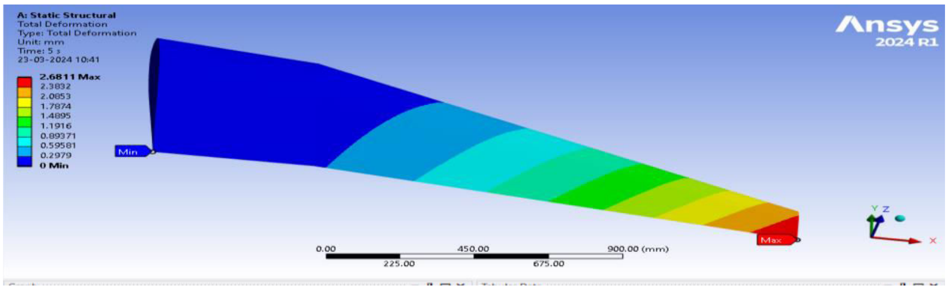

Figure 11: Total Deformation

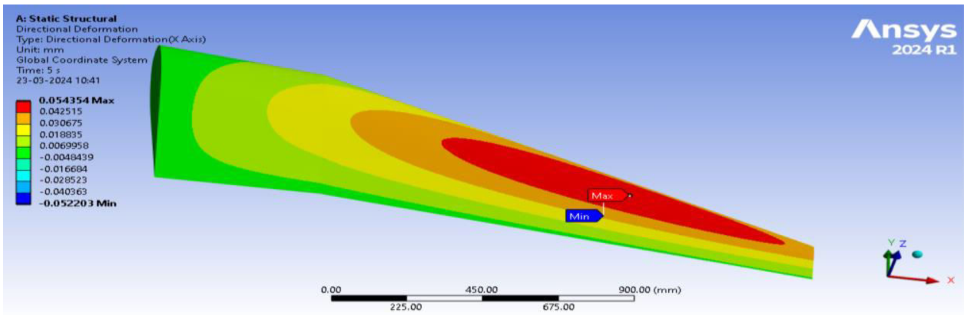

Figure 12: Directional deformation

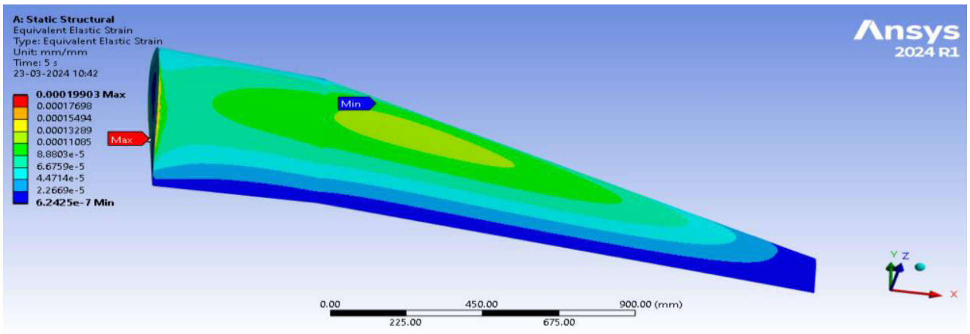

Figure 13: Equivalent elastic strain

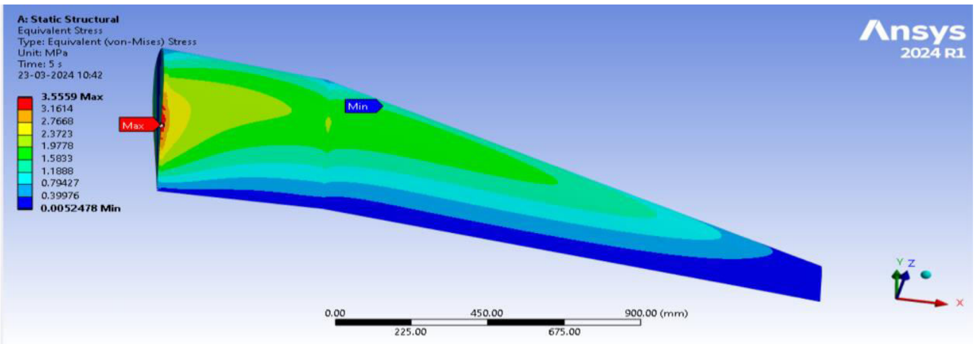

Figure 14: Equivalent stress

Static structural analysis of Aircraft wing Using Glass/Epoxy material

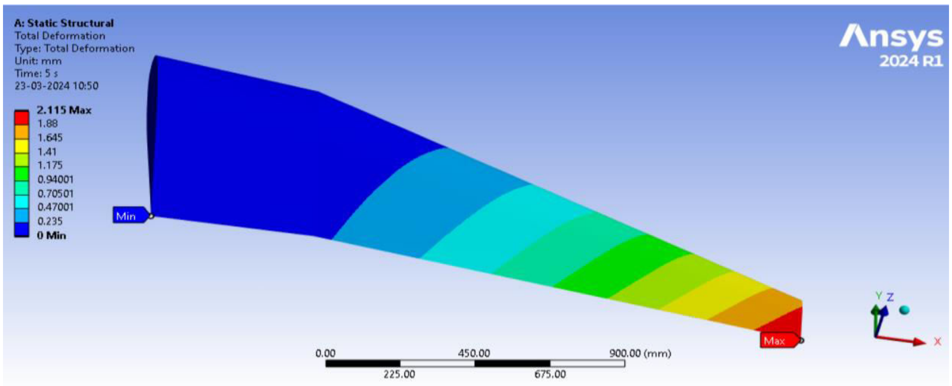

Figure 15: Total Deformation

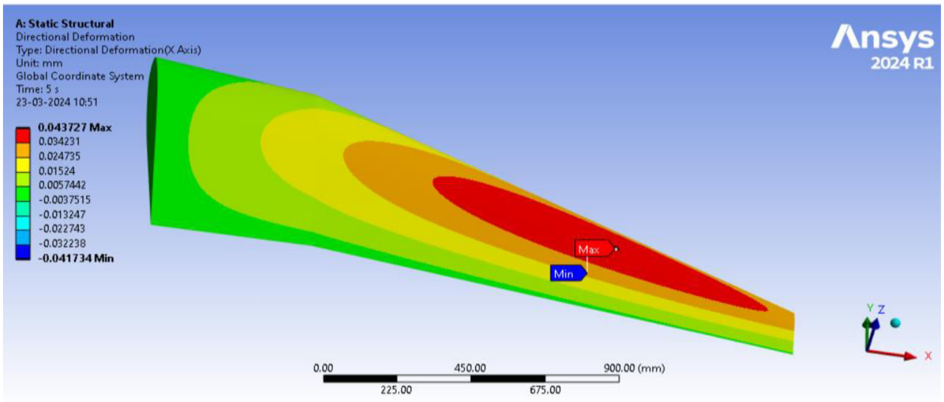

Figure 16: Directional deformation

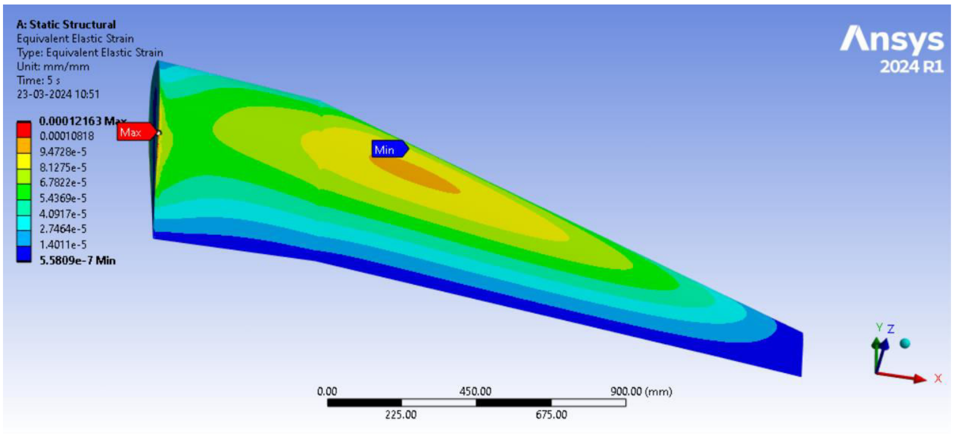

Figure 17: Equivalent elastic strain

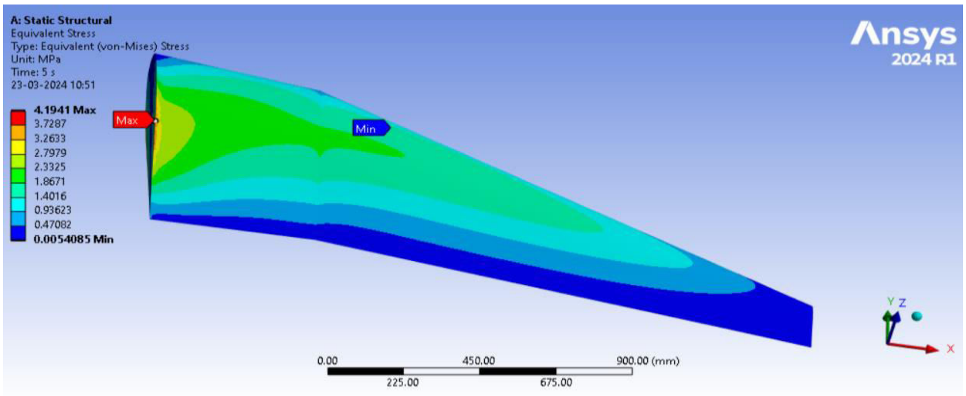

Figure 18: Equivalent stress

Table 1: Static structural analysis of Aircraft Wing Total deformations (mm) at different materials

S.No	**Material**	Total deformation (mm)	Directional deformation (mm)	Equivalent elastic strain	Equivalent stress (Mpa)
1	Kevlar fiber	3.22	4.92	2.24	**6.15**
2	Glass Epoxy	2.11	4.37	1.21	**4.19**
3	Carbon Epoxy	2.68	5.435	1.99	**3.55**

MODAL ANALYSIS OF AIRCRAFT WING

Modal analysis is a study of dynamic properties of vibrating structures. It is used to determine the natural frequency of continuous structural members. Lowest frequency mode is desired because vibration will be less as compared to higher frequency modes.

Modal analysis of Aircraft Wing using Kevlar material

In this figure observed that Kevlar material was Assignment total body after chose the model analysis using different mode conditions.

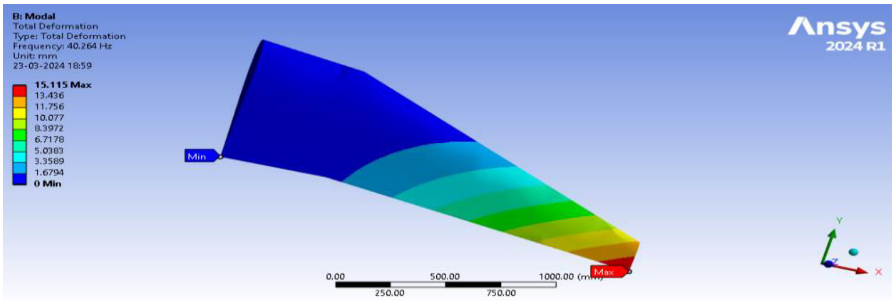

Figure 19: Frequency modal-1

In this figure clearly observed that applied the frequency 40.264 HZ with assignment material was Kevlar and the deformation moment was 15.115 max

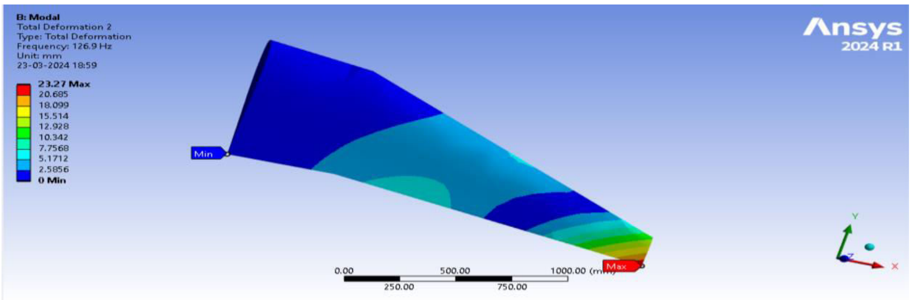

Figure 20: Frequency modal-2

The second mode of the Wing design was clearly observed that applied the frequency 126.9 HZ with assignment material was Kevlar and the deformation moment was 23.27 max

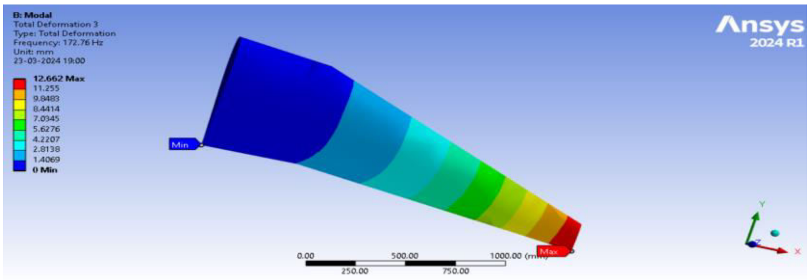

Figure 21: Frequency modal-3

In this figure observed that the third mode wing design' for which the assigned frequency was 172.76 Hz, the material was Kevlar and the maximum deformation moment was 12.662 max, was clearly detected.

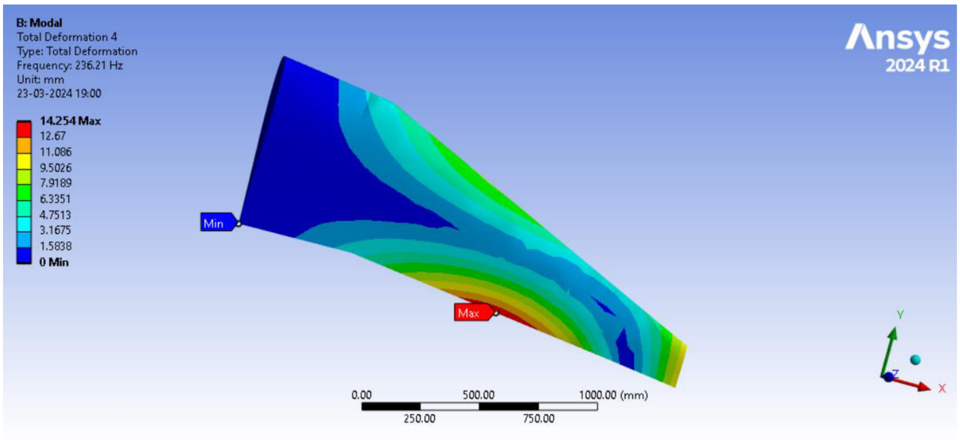

Figure 22: Frequency modal-4

The fourth mode of the design model frequency was 236.21 Hz, and the applied model deformation was 14.256 Max, as determined by modal analysis, which examines the wing inherent vibration characteristics and their dynamic features.

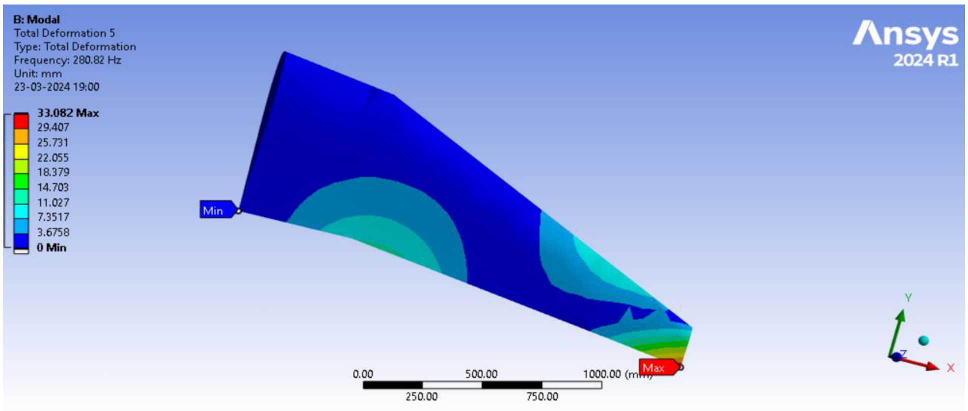

Figure 23: Frequency modal-5

The above figures show the results of the modal analysis of wing according to the Kevlar material applied the natural frequencies 280.82 Hz and the blade deformation after load condition was 33.082 Max

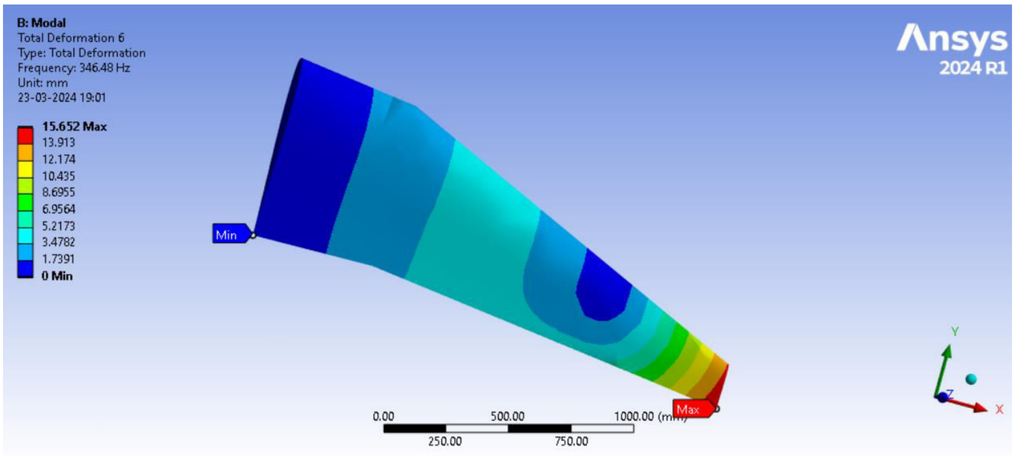

Figure 24: Frequency modal-6

The above figures show the results of the modal analysis of wing according to the Kevlar material applied the natural frequencies 346.48 Hz and the blade deformation after load condition was 15.652 Max.

Modal analysis of Aircraft Wing using Glass Epoxy material

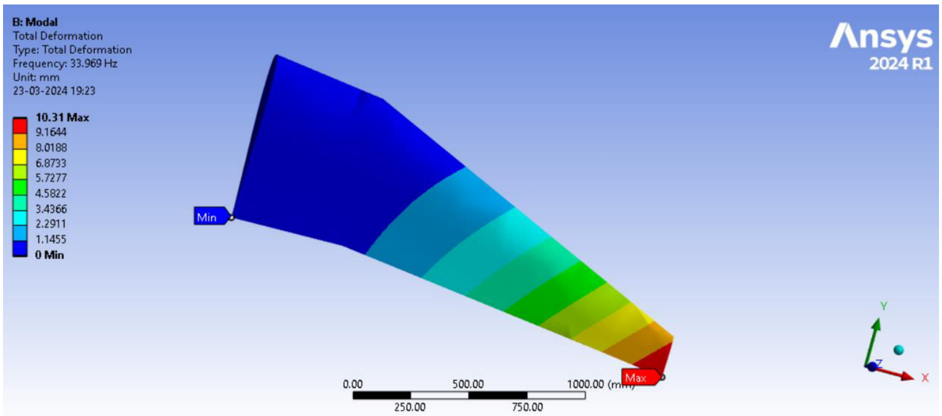

Figure 25: Static stress concentration of modal-1

In this figure clearly observed that applied the frequency 33.969 HZ with assignment material was Glass Epoxy and the deformation moment was 10.31 max

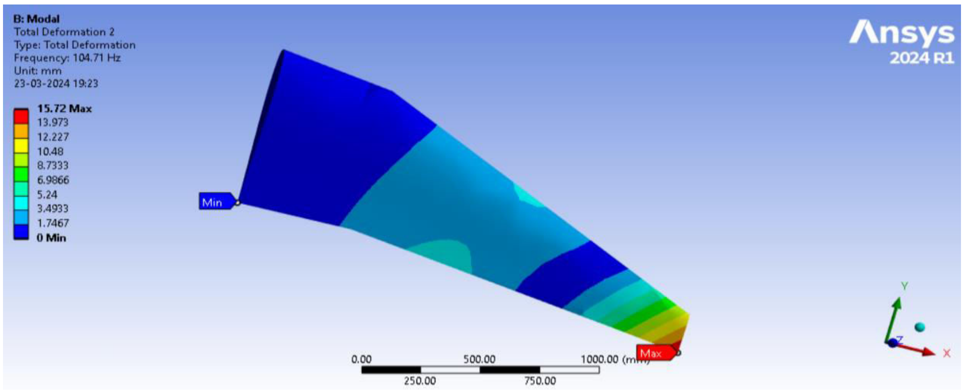

Figure 26: Static stress concentration of modal-2

The second mode of the wing design was clearly observed that applied the frequency 10.765 HZ with assignment material was carbon fiber and the deformation moment was 4.1372 max

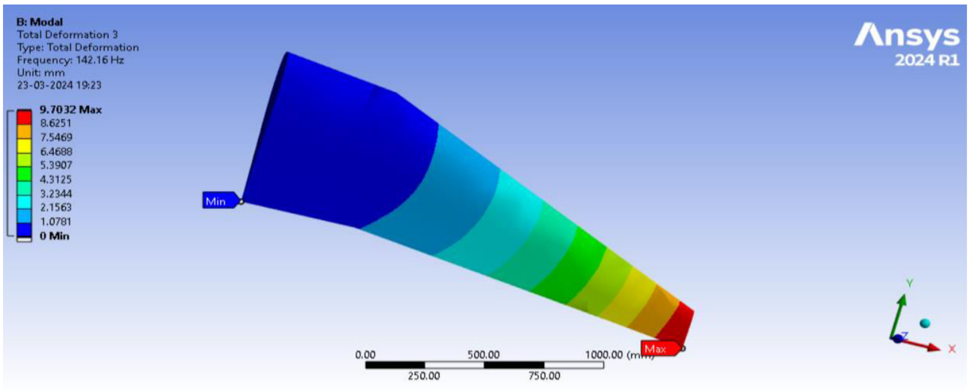

Figure 27: Static stress concentration of modal-3

In this figure observed that the third mode wing design' for which the assigned frequency was 142.16 Hz, the material was Glass Epoxy, and the maximum deformation moment was 9.7032 max, was clearly detected.

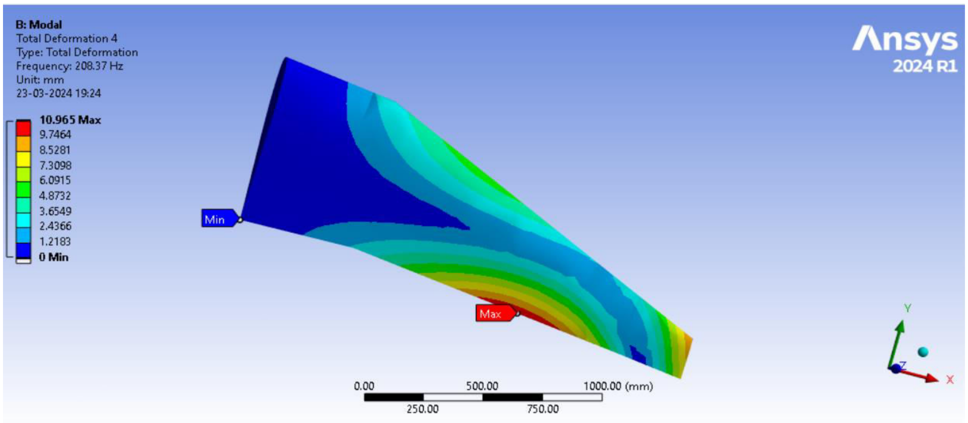

Figure 28: Static stress concentration of modal-4

The fourth mode of the blade frequency was 208.37 Hz, and the applied model deformation was 10.965 Max, as determined by modal analysis, which examines the blade inherent vibration characteristics and their dynamic features.

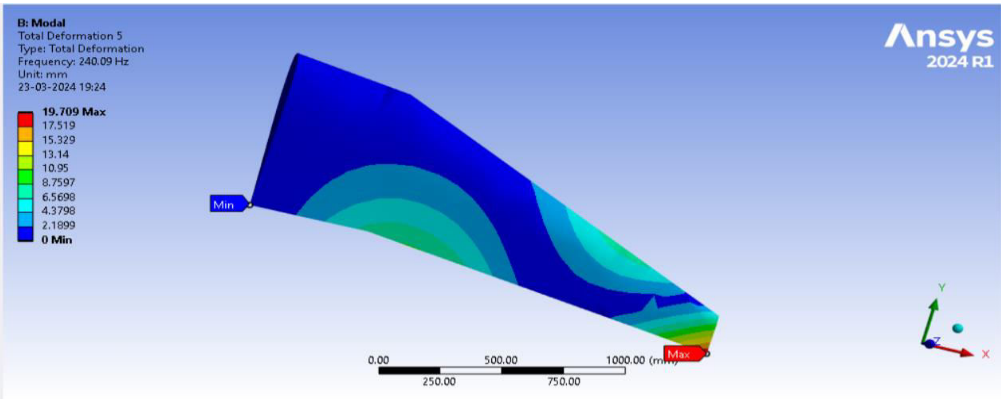

Figure 29: Static stress concentration of modal-5

The above figures show the results of the modal analysis of wing according to the Glass Epoxy material applied the natural frequencies 240.09 Hz and the blade deformation after load condition was 19.709 Max

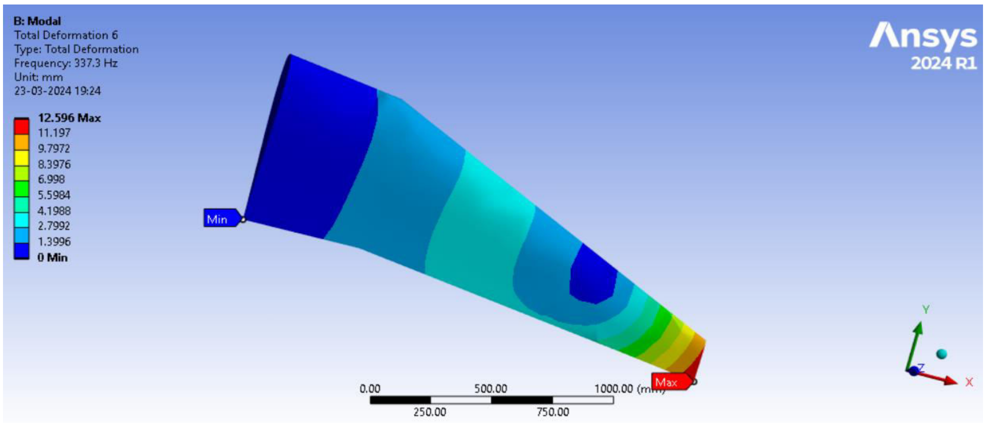

Figure 30: Static stress concentration of modal-6

The above figures show the results of the modal analysis of blade according to the Glass Epoxy material applied the natural frequencies 337.3 Hz and the blade deformation after load condition was 12.596 Max

Modal analysis of Aircraft Wing using Carbon Epoxy material

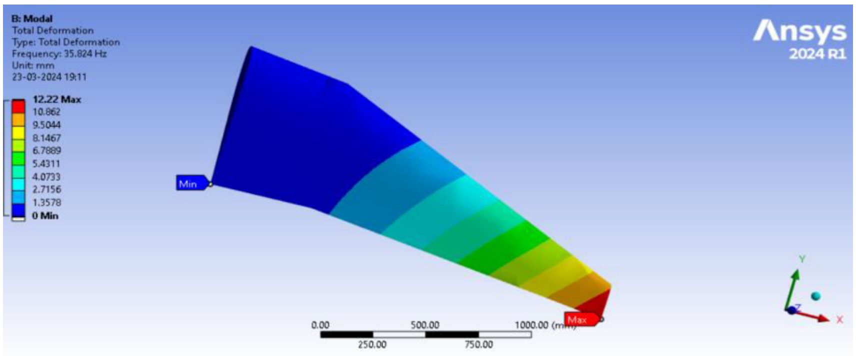

Figure 31: Static stress concentration of modal-1

In this figure clearly observed that applied the frequency 35.824 HZ with assignment material was Carbon Epoxy and the deformation moment was 12.22 max

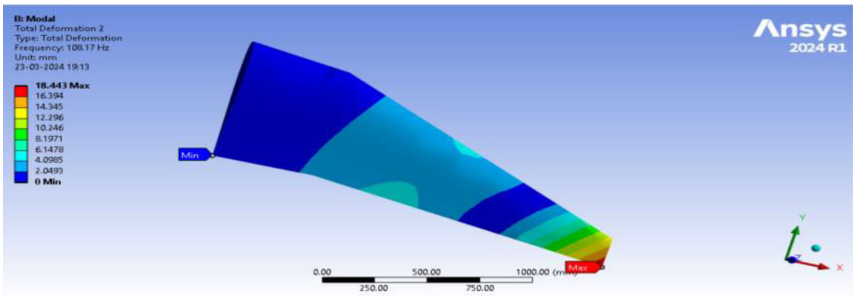

Figure 32: Static stress concentration of modal-2

The second mode of the wing design was clearly observed that applied the frequency 108.17 HZ with assignment material was Glass Epoxy and the deformation moment was 4.1372 max

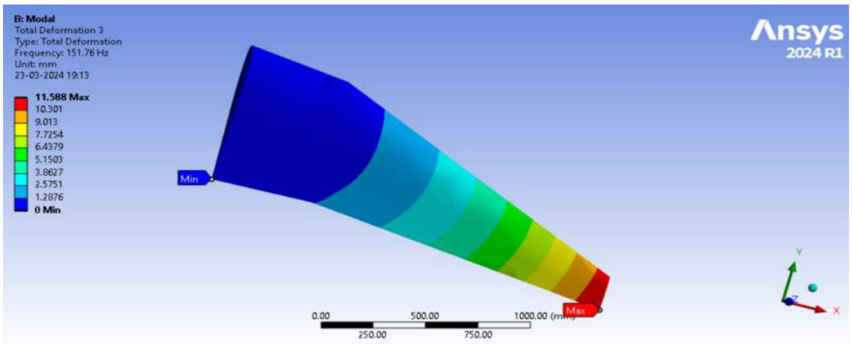

Figure 33: Static stress concentration of modal-3

In this figure observed that the third mode wing design' for which the assigned frequency was 151.76 Hz, the material was Carbon Epoxy, and the maximum deformation moment was 11.588 max, was clearly detected.

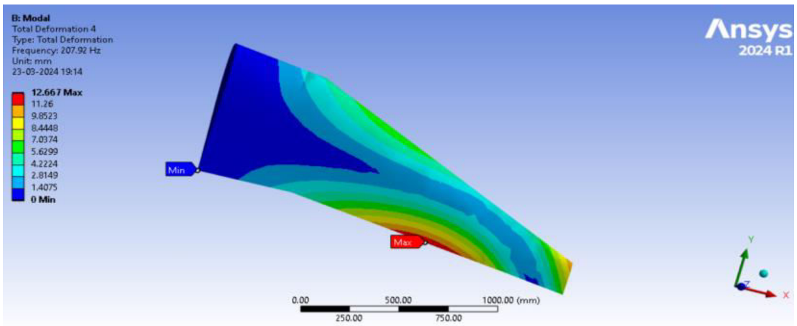

Figure 34: Static stress concentration of modal-4

The fourth mode of the wing frequency was 207.92 Hz, and the applied model deformation was 12.667 Max, as determined by modal analysis, which examines the wing inherent vibration characteristics and their dynamic features.

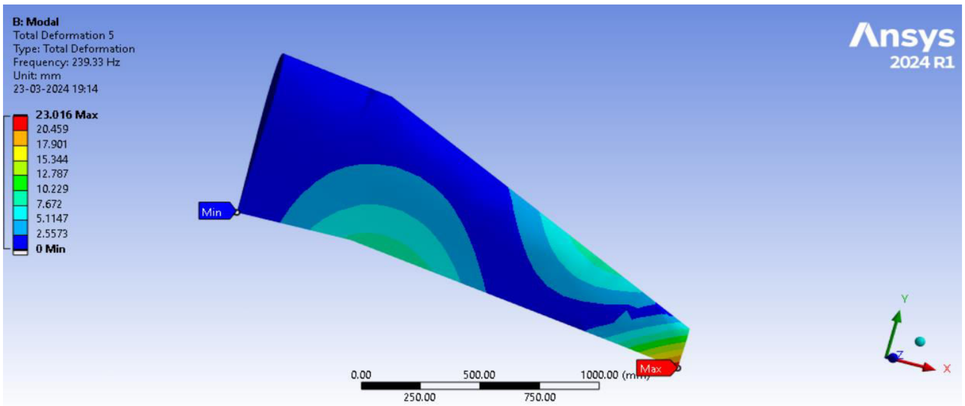

Figure 35: Static stress concentration of modal-5

The above figures show the results of the modal analysis of blade according to the Carbon Epoxy material applied the natural frequencies 239.33 Hz and the blade deformation after load condition was 23.016 Max

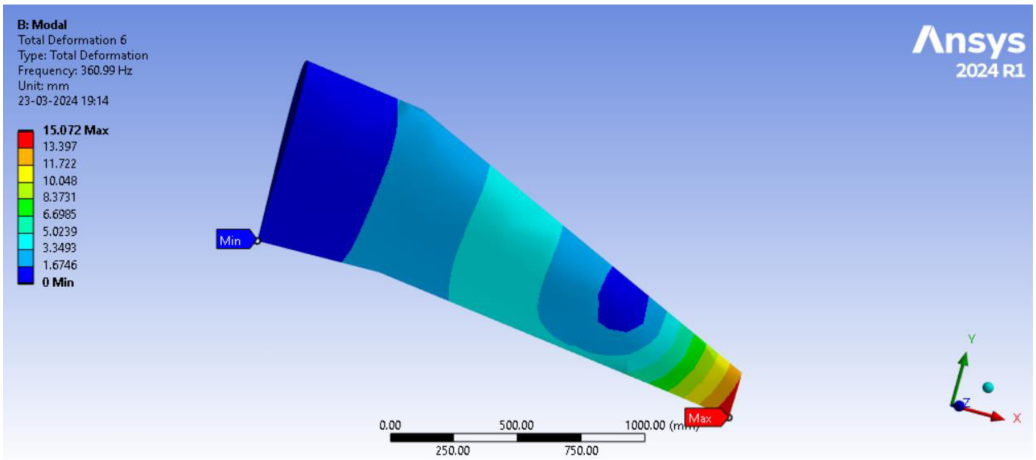

Figure 36: Static stress concentration of modal-6

The above figures show the results of the modal analysis of blade according to the Carbon Epoxy material applied the natural frequencies 360.99 Hz and the blade deformation after load condition was 15.07 Max

Table 2: Modal analysis of Aircraft Wing with different materials values in Hz from ANSYS

S. No	Modals	Kevlar (Hz)	Glass epoxy (Hz)	Carbon epoxy (Hz)
1	Modal-1 (Latitude)	15.115	10.31	12.22
2	Modal-2 (Torsion)	23.27	15.72	18.443
3	Modal-3 (Bending)	12.662	9.70	11.588
4	Modal-4 (Latitude)	14.254	10.96	12.667
5	Modal-5 (Twist)	33.082	19.70	23.016
6	Modal-6 (Longitudinal)	15.652	12.59	15.072

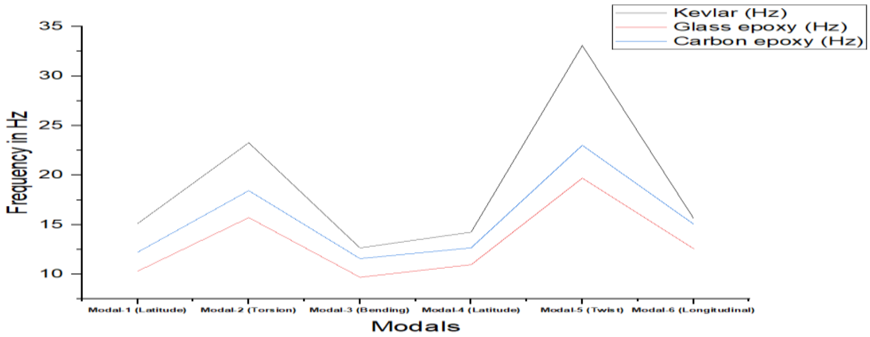

Figure 37: Validation of aircraft wing with different materials Values in Hz from ANSYS

Discussions:

- The analysis of grouped bar chart data on materials frequencies shows Kevlar has the highest average Hz (19.005), while Glass epoxy has the lowest (13.163). Carbon epoxy holds an average value (15.501 Hz).
- Kevlar shows the highest frequency with a max of 33.082 Hz in Modal-5 Twist.
- Glass epoxy dips to the lowest frequency with 9.7 Hz in Modal-3 Bending.
- Carbon epoxy's frequencies undulate, maxing at 23.016 Hz (Modal-5 Twist) and minning at 11.588 Hz (Modal-3 Bending).
- Consider using Kevlar for applications requiring higher frequency responses, Glass epoxy for lower frequencies. Further testing needed to gauge Carbon epoxy performance better.

Conclusion:

In this project the wind turbine blade modeling in Solid works parametric software and analysed for its strength using Finite Element analysis software ANSYS. Structural, and modal analysis will be done in ANSYS 2024 R1 on the different materials

The main objective of the project was to design and analysis of trapezoidal wing structure with three different materials (Kevlar, glass epoxy and Carbon epoxy).

- Finally conclude the project by saying that the material suitable for the aircraft wing is found as Carbon epoxy.
- When compare to other three materials (Kevlar, glass epoxy and Carbon epoxy) Carbon epoxy is having less deformation whenever there is self-weight is acting on it. Finally, Carbon epoxy is the efficient material for the aircraft wing

From the above obtained result that carbon epoxy provide more strength to the wing when it is morphed along with ribs and spar by providing maximum yield capacity and long life. It indirectly defines that good airworthiness and valuable strength to the aircraft by using Carbon Epoxy the acceptable material strength of carbon epoxy is 600-900 Mpa at compression and 750-1600 Mpa at tension.

Future scope:

The future wing for design aircraft poses many new challenges in configuration design, use of materials, design and analysis methods. These challenges can be met, while adhering to all regulatory requirements of safety, by employing advanced technologies, materials, analysis methods, processes and production methods. By applying functional simulation and developing design tools, the development time and cost reduced considerably

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